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Fault detection and isolation for a railway vehicle by evaluating estimation residuals

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Abstract

The capacity of transport as well as the number of passengers is growing in the railway industry. At the same time, the pressure to reduce service costs rises. Reliability and dependability in complex mechanical systems can be improved by fault detection and isolation methods (FDI). These techniques are key elements for maintenance on demand, which could decrease service cost and time significantly. This work addresses FDI for a railway vehicle: The mechanical model is described as a multibody system, which is excited randomly due to track irregularities. The aim of this work is to detect faults in the suspension system of the vehicle. A Kalman filter is used to estimate the states. In order to detect and isolate faults, the detection error is minimized with multiple Kalman filters. A full scale train model with nonlinear wheel rail contact and nonlinear suspension forces serves as an example for the described techniques. Numerical results for different test cases are presented. For the analysed system it is possible not only to detect a failure of the suspension system from the system's dynamic response, but also to distinguish clearly between different possible causes for the changes in the dynamical behavior.

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Keywords: fault detection and isolation; Multiple Kalman filters; railway vehicle dynamics; maintenance;

1. Introduction

This work presents a method to detect and isolate faults in a railway vehicle model. Such a method could be used to increasing system reliability and dependability. On-line fault detection and isolation (FDI) offers advantages, when early detection of faults and wear is crucial. This not only improves system reliability, it also saves maintenance costs and time.

Parameter estimation using a Rao-Blackwellized Particle filter and Extended Kalman Filter [1,2,3] gives good results for linear and nonlinear suspension systems using a two dimensional linear model. A multiple-model algorithm to detect faults is given in [4,5,6], the model used for the fault detection is a two dimensional half train model. FDI methods for the handling of damping coefficients are described in [7,8]: Depending on the sign of the relative damper velocity, the coefficients switch between two distinct values. Suspension parameter estimation in frequency domain is presented

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in[9]. Model-less monitoring methods for railway vehicles are demonstrated in[10,11,12]. A comparative study on fault detection methods of urban rail vehicle suspension systems is presented in[13]. The fault detection methods applied to a three dimensional vehicle but only tested for the case, that all four primary suspension springs or all four secondary suspension dampers fail at the same time. A Hybrid Extended Kalman filter for fault detection in nonlinear suspension elements for a half train model is given in[14].

The aim of this work is to detect and isolate faults in the suspension elements fixed at the train. More precisely, the aim is to detect faults in the anti-yaw damper, the secondary vertical damper and the secondary lateral damper. The first one, the anti-yaw damper, is very important for running stability, while the second and third one are influencing ride quality. A full scale railway vehicle model is excited randomly to model track irregularities. Acceleration sensors provide the data for the state estimation with several Kalman filters. In order to improve the state estimation process, the characteristics of the track irregularities are considered in the fault detection process. For the fault detection and isolation procedure, the state observation is performed with different systems. One of the systems represents the fault free case, the other systems represent the faults, which should be detected. Faults are detected and isolated by minimizing the estimation error. Out of all available models the one, which minimizes the estimation error, is selected. With this approach, faults in the suspension system can be detected and isolated accurately. Furthermore, it is possible to distinguish between a large number of different faults. A single fault at a single suspension can be identified as well as multiple failures in the three dimensional suspension system.

2. Vehicle dynamics

To test the proposed method, a full scale train model with nonlinear wheel rail contact and nonlinear suspension forces is used. The Velaro RUS serves as an example. In this section, the dynamic model of the train is described, which can be divided into two parts: the multibody system of the train itself and the description of the track with its irregularities.

2.1. Multibody system

The train model of the Velaro RUS consists of a car body, two bogies, four wheelsets and two motors. Car body, bogie and motor motion can be characterized by six degrees of freedom each. By assuming constant running speed and constant rotational motion of the wheelsets around the y-axis, the wheelset motion is considered as four dimensional.

The wheelsets are connected to the bogies by the so-called primary suspension, the connection between the bogies and the car body is the secondary suspension. Another suspension is to be found between the motor and the bogie. Figure 1 shows the suspension structure of the bogies, the position of the three dampers, the anti-yaw damper, the secondary lateral damper and the secondary vertical damper, which are used for the fault detection.

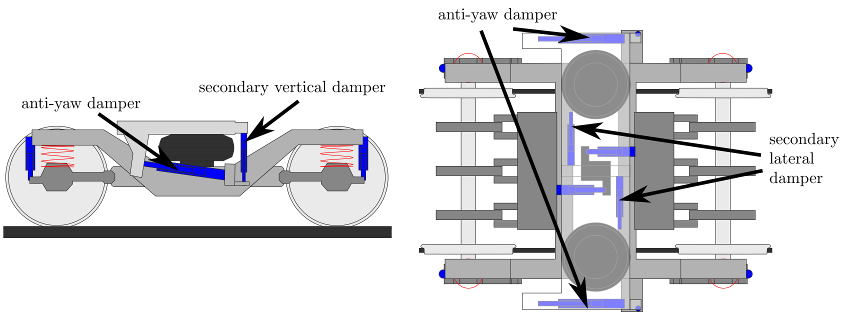

Fig. 1. Bogie: Side view

The Newton-Euler equations are used to derive the equations of motion. The origin of the body coordinate system is located at the center of mass of the body. The Newton-Euler equations of motion for a rigid single body are given in matrix form as follows[15]